Treatment of complex coarctation and coarctation with cardiac lesions using extra-anatomic aortic bypass

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Background: **Coarctation of the aorta with cardiac lesions or complex coarctation is a formidable challenge for cardiac surgeons. Extra-anatomic bypass allows simultaneous intracardiac repair or an alternative approach for patients with complex coarctation.**

Methods: **Between July 1997 and March 2008, 43 patients with coarctation of the aorta underwent extra-anatomic bypass grafting, including 10 ascending-to-descending aorta bypasses and 33 ascending aorta-to-infrarenal abdominal aorta bypasses. Forty patients had additional cardiovascular disorders and concomitant procedures performed including aortic valve replacement, mitral valve replacement, coronary artery bypass grafting, closure of ventricular septal defect and patent ductus arteriosus, ascending aorta repair, and the Bentall procedure. The other three patients had complex coarctation of the aorta, including a long-segment coarctation in two cases, and descending aortic aneurysm in one.**

Results: **Two patients died perioperatively: one due to air embolism during the cardiopulmonary bypass; one due to septic shock. There were no late deaths. Complications included laparotomy for mechanical ileus in one and re-exploration for bleeding in one case. There were no strokes or paraplegia and no grafted-related complication during follow-up period. Systolic blood pressure dropped from 160 ± 27 mm Hg before surgery to 114 ± 16 mm Hg postoperatively. Only two patients with mild hypertension postoperatively needed oral medicine.**

Conclusions: **Extra-anatomic aortic bypass via median sternotomy or median sternotomy-laparotomy can be performed with low morbidity and mortality. It is a preferable single-stage approach for patients with concomitant complex coarctation and cardiovascular disorders. (J Vasc Surg 2010;51:1203-8.)**

Coarctation of the aorta is commonly associated with congenital and acquired cardiac lesions that may require surgical intervention. In addition, 5% to 30% of patients with previous repair for coarctation have recoarctation and require reintervention.[1-3] Currently, no consensus has been reached about the best treatment for patients with both significant coarctation or recoarctation with concomitant cardiovascular diseases. Several surgical approaches have been described for the management of these patients, including options of a staged procedure using both median sternotomy and left thoracotomy, a catheter-based intervention of the coarctation combined with sternotomy, and single-stage simultaneous correction of both lesions via sternotomy. Extra-anatomic bypass grafting techniques have been accepted by most cardiac surgeons. This article reports our experience with two kinds of extra-anatomic bypass: ascending-to-descending aortic bypass and ascending-to-infrarenal abdominal aortic bypass in 43 consecutive patients.

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MATERIALS AND METHODS

The clinical, surgical, and follow-up records of 43 patients were compared with those who underwent extra-anatomic aortic bypass grafting through a median sternotomy or median sternotomy-laparotomy for repair of coarctation of the aorta between July 1997 and March 2008 in our institute. There were 25 males and 18 females with a mean age of 32 ± 12 years (range, 11 to 58). Before the operation, the cardiac functions were categorized as functional class I to III of New York Heart Association. All patients had systemic hypertension; the mean systolic blood pressure was 160 ± 27 mm Hg preoperatively. The preoperative medications included β-receptor antagonist and calcium channel blocker. No patient suffered renal dysfunction preoperatively. Two patients had previous cardiovascular operations, one patient had repair of aortic arch hypoplasia, and one patient had closure of ventricular septal detect. No patient was treated previously with endovascular techniques. The demographic characteristics of the patients are listed in Table I. Clinical characteristics are listed in Tables II to V. The coarctation was found to be in the descending thoracic aorta in 41 patients, and hypoplasia of aortic arch in two patients. The etiology was congenital in 39 and Takayasu's arteritis in four cases. Thirty-six patients with cardiac disorders included heart valve disease in 15 (Table II); ascending aortic aneurysm in 9 (Table III); and

Table I. Demographic characteristics of the patients

Characteristics	*Number of patients or value*	*%*
Mean age (range), year	32 ± 12 (11 to 58)	
Sex		
Male	25	58%
Female	18	42%
Hypertension	43	100%
Preoperative NYHA functional class		
I	12	28%
II	21	49%
III	10	23%
IV	0	0

congenital heart disease in 12 (Table IV). Seven patients with complex coarctation included recoarctation in 1; Takayasu's arteritis in 4 (patients with Takayasu's arteritis had long or multiple coarctation); descending aorta aneurysm nearby coarctation in 1 (descending aortic aneurysm was post-stenotic dilation); and right subclavian artery pseudoaneurysm in 1 (the reason of subclavian pseudoaneurysm formation might be trauma) (Table V). Preoperative evaluation included clinical examination, transthoracic echocardiography, angio-computed tomography (CT) scan, and coronary angiography. The institutional ethic committee approved this study and waived individual consent for this retrospective analysis.

Follow-up was conducted either via direct patients contact or by telephone interview with the patient and the referring physician. All patients had CT scan before discharge and at 1 year postoperatively. The patients were required to have CT scan every year until 3 years postoperatively, which was achieved by 85%(35/41) of the patients. After the postoperative third year, the graft and the aorta were assessed by vascular ultrasound aperiodically.

There were two indications for extra-anatomic aortic bypass grafting in this series. The first indication was coarctation with cardiac problems that required repair through median sternotomy or median sternotomy-laparotomy. The second indication was complex coarctation which extra-anatomic bypass grafting was chosen because of the anticipated difficulties with direct anatomic repair.[4] Complex coarctation include (1) long or multiple coarctation, (2) recoarctation, and (3) aneurysm formation nearby coarctation.

Operative techniques. Two techniques of extra-anatomic aortic bypass techniques were applied: ascending-to-descending aortic bypass in 10 patients and ascending-to-infrarenal abdominal aortic bypass in 33 patients.

Our ascending-to-descending aortic bypass was performed through a median sternotomy with hypothermic cardiopulmonary bypass. After cardiopulmonary bypass was established, the ascending aorta was cross-clamped, and antegrade blood cardioplegia was used to arrest the heart. The heart was retracted cephalad and to the patient's right. The posterior pericardium was incised longitudinally directly over the descending thoracic aorta. The aorta was dissected to allow placement of a partially occluding vascular clamp. Unnecessary dissection in the region of the esophagus was avoided, and an end-to-side graft-to-aorta anastomosis was made using a continuous 4-0 polypropylene suture. The graft was allowed to fill retrograde, and a clamp was placed on its proximal portion. Then, concomitant intracardiac repair was performed. Upon the completion of those procedures, the ascending aortic cross-clamp was removed after de-airing of the heart. The graft was routed anterior to the inferior vena cava and led around the right atrium and anastomosed to the right lateral aspect of the ascending aorta (Fig 1). The average size of bypass graft was 16 ± 2 mm (range, 14 to 18). The mean cross-clamp time was 85 ± 37 minutes (range, 35 to 142). The mean cardiopulmonary bypass (CPB) time was 134 ± 40 minutes (range, 65 to 186).

The ascending-to-infrarenal abdominal aortic bypass was performed through a median sternotomy-laparotomy. The operation was performed with the patient in a supine position. A midline incision was made from the suprasternal notch to a point about a half between the navel and the pubis. After the peritoneal cavity was entered, the infrarenal abdominal aorta was selected as the site of distal anastomosis (Fig 2). With the aid of a partially occluding clamp, a vascular prosthesis was anastomosed to the infrarenal abdominal aorta in an end-to-side manner. After CPB was instituted, the intracardiac lesion was repaired on CPB. Care was taken to ensure that the anastomotic site within the abdomen was retroperitoneal and well covered with peritoneum. After that, the graft was routed around the duodenum at the ligament of Treitz and through the transverse mesocolon into the lesser sac, passed posteriorly to the stomach, and then curving anteriorly to pass through the gastrohepatic mesentery (between the stomach and the liver). It was then passed through a hole in the diaphragm to course anteriorly to the right atrium before being anastomosed end-to-side to the partially clamped ascending aorta. If there was no concomitant intracardiac disorder, ascending-to-infrarenal abdominal aortic bypass was performed in the same way without CPB. The operation was finished with closing of the chest and abdomen in the standard manner. The average size of bypass graft was 16 ± 2 mm (range, 14 to 18). The mean cross-clamp time was 61 ± 17 minutes (range, 35 to 95) and the mean CPB time was 93 ± 28 minutes (range, 52 to 160).

Polyester grafts were used (16-18 mm graft for the adult, 14 mm for adolescent). In our series, there are two 11-year patients and four teenagers, in whom we tried to allow sufficient redundant graft to avoid problems using ascending-to-infrarenal abdominal aortic bypass grafting. The redundancy of graft for pre-adult patients was created by excessive "bowing" of these grafts, which has not been associated with excessive bypass motion. Because the graft was routed into the minor omentum, passed posterior to the stomach, then passed through a hole in the diaphragm, it was wrapped by nearby organs.

Table II. Heart valve disease: preoperative diagnosis, procedures, and results

Patient	*Sex*	*Age (year)*	*Diagnosis*	*Procedure*	*Complication/ Mortality*
1	M	11	MI, COA	MVR, aAo-mAo	none
2	F	13	AI, COA	AVR, aAo-mAo	none
3	F	18	SAS, MI, COA	MVP, AAP, aAo-mAo	none
4	F	22	MI, COA	MVP, aAo-dAo	none
5	M	22	MI, AI, COA	MVR, AVR, aAo-dAo	none
6	M	27	AS, AI, COA	AVR, aAo-dAo	none
7	M	35	AS, COA	AVR, aAo-mAo	Re-exploration for ileus
8	F	35	AS, COA	AVR, aAo-dAo	none
9	M	36	AI, COA	AVR, aAo-mAo	none
10	F	37	AS, AI, COA	AVR, aAo-dAo	none
11	F	37	MI, AF, COA	MVR, aAo-mAo	none
12	M	39	AS, AI, COA	AVR, aAo-dAo	none
13	F	42	MI, MS, COA	MVR, aAo-dAo	none
14	M	43	AS, COA	AVR, aAo-mAo	none
15	F	54	AS, AF, CAD, COA	AVR, aAo-dAo, CABG	Re-exploration for bleeding

aAo-mAo, Ascending-to-infrarenal abdominal aortic bypass; *aAo-dAo,* ascending-to-descending aortic bypass; *SAS,* supravalvular aortic stenosis; *AAP,* ascending aorta plasty; *COA,* coarctation of aorta; *AF,* atrial fibrillation; *CAD,* coronary artery disease; *CABG,* coronary artery bypass grafting; *MI,* mitral insufficiency; *MS,* mitral stenosis; *AI,* aortic insufficiency; *AS,* aortic stenosis; *AVR,* aortic valve replacement; *MVR,* mitral valve replacement.

Table III. Ascending aorta aneurysm or aortic root aneurysm: preoperative diagnosis, procedures, and results

Patient	*Sex*	*Age (year)*	*Diagnosis*	*Procedures*	*Complication/Mortality*
1	M	26	aAoa, COA	aAoR, aAo-mAo	none
2	F	26	BAV, AS, AI, aAoa, COA, after VSD closure	Bentall, aAo-mAo	none
3	M	27	BAV, AS, AI, aAoa, COA	AVR, AAP, aAo-mAo	none
4	M	32	AI, aAoa, COA	Bentall, aAo-mAo	none
5	M	34	ARA, AI, COA	Bentall, aAo-dAo	died of septic shock
6	M	44	ARA, AI, COA	Bentall, aAo-mAo	none
7	M	45	α-AD, ARA, AI, COA	Bentall, aAo-mAo	none
8	M	45	AF, ARA, AI, COA	Bentall, aAo-dAo	none
9	F	50	AI, aAoa, COA	Bentall, PAAR, aAo-dAo	none

aAoa, Ascending aorta aneurysm; *ARA,* aortic root aneurysm; *BAV,* bicuspid aortic valve; VSD, ventricular septal defect; *aAo-mAo,* ascending-to-infrarenal abdominal aortic bypass; *aAo-dAo,* ascending-to-descending aortic bypass; *COA,* coarctation of aorta; *AF,* atrial fibrillation; *CAD,* coronary artery disease; *AI,* aortic insufficiency; ‖*-AD,* Debakey ‖ aortic dissection; *AAP,* ascending aorta plasty; *PAAR,* partially aortic arch replacement; *AVR,* aortic valve replacement.

Table IV. Congenital heart disease: preoperative diagnosis, procedure, and results

Patient	*Sex*	*Age (year)*	*Diagnosis*	*Procedure*	*Complication/Mortality*
1	F	11	VSD, PDA, COA	Closure of VSD and PDA, aAo-mAo	none
2	M	13	BAV, AS, MI, PDA, HPAA	AVR, MVP, PDA closure, aAo-mAo	none
3	M	16	PDA, parasol MV, COA	MVR, PDA closure, aAo-mAo	residual hpertension
4	F	18	MI, SAS, COA	MVP, AAP, aAo-mAo	none
5	M	19	AS, VSD, PDA, COA	AVR, closure of VSD and PDA, aAo-mAo	died of gas embolism
6	F	19	VSD, PDA, COA	Closure of VSD and PDA, aAo-mAo	none
7	F	21	MS, MI, VSD, PDA, COA	MVR, closure of VSD and PDA, aAo-mAo	none
8	M	25	AVS, BAV, TI, COA	AVR, TVP, AVS closure, aAo-mAo	none
9	M	32	PDA, MI, TI, COA	MVR, TVP, PDA closure, aAo-mAo	none
10	M	35	VSD, AI, COA	AVR, VSD closure, aAo-mAo	none
11	M	37	VSD, AI, COA	AVR, VSD closure, aAo-mAo	none
12	F	39	PDA, COA	PDA closure, aAo-mAo	none

aAo-mAo, Ascending-to-infrarenal abdominal aortic bypass; *aAo-dAo,* ascending-to-descending aortic bypass; *HPAA,* hypoplasia of aortic arch; *BAV,* bicuspid aortic valve; *VSD,* ventricular septal defect; *PDA,* patent ductus arteriosus; *AVR,* aortic valve replacement; *MVP,* mitral valve plasty; AVS, aneurysm of valsalva sinus; *TI,* tricuspid insufficiency; *MVR,* mitral valve replacement; *MI,* mitral insufficiency; *MS,* mitral stenosis; *AI,* aortic insufficiency; *AS,* aortic stenosis.

RESULTS

There were two in-hospital deaths in the series with a mortality of 4.6% (2/43). In the first patient, CPB was established with double arterial cannulation using separate dual pumps. However, the connection and perfusion technique employed for the separate dual pumps was a slightly complicated, and the patient died of air embolism in the arterial line due to an accident during the CPB process.

Table V. Complex COA: preoperative diagnosis, procedure, and results

12	*Sex*	*Age (year)*	*Diagnosis*	*Procedure*	*Complication/Mortality*
1	F	19	Takayasu's arteritis, LMO, COA	CABG, aAo-mAo	None
2	F	30	Takayasu's arteritis, long COA	aAo-mAo	None
3	M	30	Takayasu's arteritis, long COA	aAo-mAo	None
4	F	41	COA, DAA	aAo-mAo	None
5	M	50	BAV, AS, Takayasu's arteritis, CAS, COA	AVR, CABG, aAo-mAo	None
6	M	58	RSAP, COA	RSAP excision, aAo-mAo	None
7	M	52	BAV, AI, RPHAAR	AVR, aAo-mAo	residual hpertension

LMO, Left main occlusion; *CABG,* coronary artery bypass grafting; *COA,* coarctation of aorta; *DAA,* descending aorta aneurysm; *aAo-mAo,* ascending-to-infrarenal abdominal aortic bypass; *CAS,* coronary artery stenosis; *AS,* aortic stenosis; *RSAP,* right subclavian artery pseudoaneurysm; *RPHAAR,* restenosis after repair of aortic arch hypoplasia; *BAV,* bicuspid aortic valve; *AI,* aortic insufficiency.

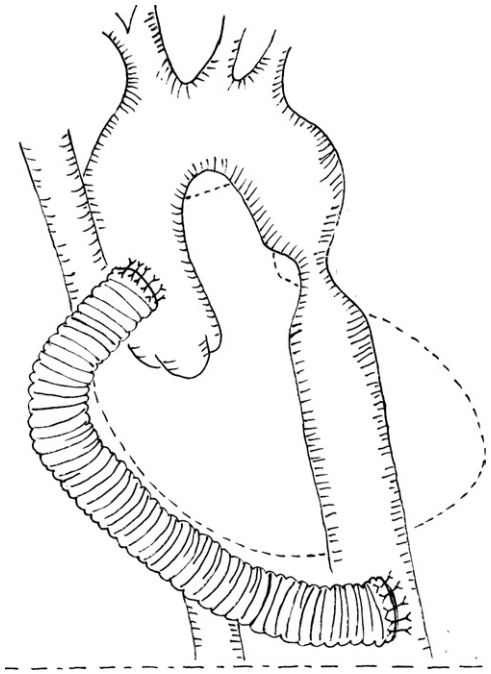

Fig 1. Ascending-to-descending aortic bypass: the graft was routed anteriorly to the inferior vena cava. The graft was led around the right atrium and anastomosed to the right lateral aspect of aspect of ascending aorta.

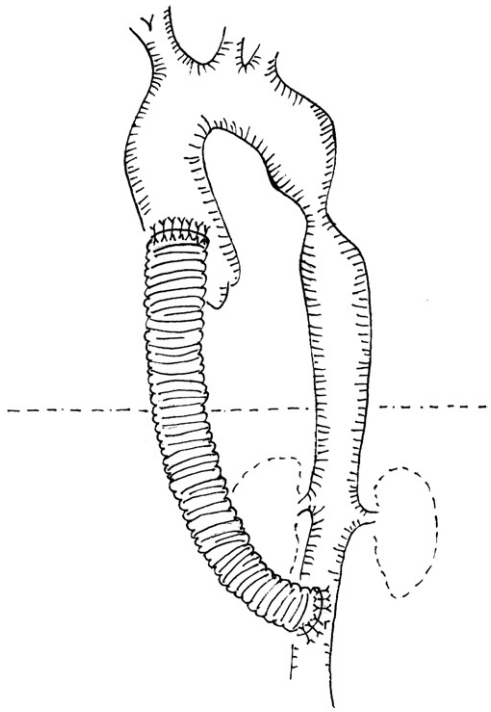

Fig 2. Ascending-to-infrarenal abdominal aortic bypass: the infrarenal abdominal aorta was chosen as the site of distal anastomosis.

After this incident, separate dual pumps were omitted and a single pump-dual conduit was used. The second patient died of intractable septic shock caused by infection of the anastomotic site between the graft and the descending aorta, which could not be visualized clearly at re-exploration. We had to use gauze for hemostasis and the sternum was closed 2 days later. The gauze used to stop the bleeding, hematoma, and delayed closure of incision were presumed to be the source of infection. All other patients survived during the follow-up period. Early postoperative morbidity included bleeding in one patient and mechanical ileus in one patient. The patient suffered from bleeding at the anastomotic site between the graft and the descending aorta postoperatively. During re-exploration, it was difficult to control the bleeding with the heart beating and CPB had to be employed. The patient suffered from partial intestinal obstruction postoperatively and underwent surgery 6 days later. During the reoperation, part of the jejunum was seen trapped in the hole left by the drainage tube; the graft was intact. This patient made a good recovery. There were no instances of postoperative paraplegia and permanent abnormalities upon the neurologic examination. Concomitant intracardiac lesions were treated successfully in the surviving patients who were discharged in good condition. The average length of hospital stay was 12 ± 3 days.

Follow-up was completed for 41 patients, with a mean follow-up period of 53 ± 31 months and a maximum of 144 months. There were no late deaths. No reoperation was required. One year after extra-anatomic bypass, spon-

taneous thrombosis inside the aneurysm in the patient who had coarctation with descending aortic aneurysm was shown by CT scan. We thought the reason of spontaneous thrombosis was that the blood flow inside aneurysm was slower after the bypass procedure. We believe the patient is safe from aneurysm rupture. Because of thrombosis and slower blood flow, the pressure inside the ascending thoracic aneurysm was decreased obviously. No late graft-related complications occurred. There were no other non-graft, procedural major complications (MI, arrhythmias, pneumonia, etc). At follow-up, vascular ultrasound and computerized tomography demonstrated patency in all grafts.

In the six adolescent patients, the mean follow-up duration was 104 ± 31 months, the max duration was 144 months, and the minimum duration was 64 months. When axial growth exceeds graft redundancy, the excessive bowing of grafts disappeared gradually. Then, the infrarenal abdominal aorta was stretched into an arch-shape with anastomotic site being at the top of arch while the ascending aorta did not change. The arch-shaped infrarenal abdominal aorta was found by vascular ultrasound because we did not have CT scan after postoperative year 3.

There was a significant reduction in mean upper extremity blood pressure after coarctation repair with extra-anatomic aortic bypass. Systolic blood pressure decreased from 160 ± 27 mm Hg preoperatively to 114 ± 16 mm Hg postoperatively ($P < .001$). There were only two patients who needed oral antihypertensive medications because of mild hypertension. Other patients are asymptomatic.

DISCUSSION

Although Crawford performed the first surgical correction of coarctation as early as in 1944, and the treatment of aortic coarctation has improved significantly during the last 60 years, currently, no consensus has been reached about the best treatment for patients with complex coarctation or coarctation with cardiac problems. Several surgical approaches have been described for the management of these patients, including staged procedure using both median sternotomy and left thoracotomy, catheter-based intervention of the coarctation combined with sternotomy, and single-stage simultaneous correction of both lesions via a midline incision.

For a long time, patients with both coarctation and cardiac defects have required two separated surgical procedures, each with its own inherent risks and costs. Furthermore, the selection of which lesion to correct first can be of critical importance. We believe that the cardiac defects in our patients were significant enough that a staged approach with primary repair of the coarctation would have produced marked hemodynamic instability and likely mortality. Operating on the cardiac defect without addressing the significant coarctation might lead to significant underperfusion of organs distal to the coarctation and leave the left ventricle with a severe pressure load due to late hypertension and cause congestive heart failure as well. However, using the technique of extra-anatomic bypass graft, both lesions can be repaired simultaneously. Although Pethig and coworkers[5] reported heart failure and life-threatening ventricular arrhythmias after simultaneous surgical repairs caused by myocardial hypoperfusion consequent to an acute reduction in the afterload, this phenomenon was not observed in our patients, since weaning from cardiopulmonary bypass is done according to the generally accepted practice; vasoconstrictors are used to increase afterload to minimize rapid runoff in the new conduit in our hospital. So we believe that simultaneous repair of both lesions would be the optimal curative procedure.

Complex forms of coarctation have been surgically approached by using anatomic repair and extra-anatomic bypass grafting. Anatomic repair may be complicated due to the need for extensive mobilization of the aorta, control of collateral blood vessels, the potential of parenchymal lung injury, damage to the recurrent laryngeal or phrenic nerves, chylothorax, and spinal cord ischemia. The most frightful complication of anatomic repair is paraplegia and the risk of spinal cord injury. The risk of these complications increases with prolonged aortic cross-clamp time and older age.[6] Extensive dissection and cross-clamping of the aorta are avoided by employing the extra-anatomic bypass technique. A side-biting aortic clamp allows continuation of blood flow to the posterior wall of the aorta and to the intercostal arteries, which, in turn, reduces the risk of paraplegia. Ascending-to-infrarenal abdominal aorta bypass grafting was used, and no paraplegia and other serious complications occurred in our complex coarctation patients.

Since Siderys and associates reported extra-anatomic bypass from the ascending aorta to the abdominal aorta, distal to the renal arteries in 1974,[7] and Vijayanagar et al[8] described the extra-anatomic bypass from the ascending aorta to the descending aorta through a median sternotomy and posterior pericardium in 1980, various bypass grafting methods from the ascending aorta or the subclavian or axillary arteries to the descending thoracic or abdominal aorta, or the femoral artery have been described.

Ascending-to-descending aortic bypass grafting has the following advantages. First, bypass grafting and concomitant cardiovascular disorders repair are accomplished at the same time through one short sternotomy. Second, there is no need of laparotomy, which avoids affecting peritoneal organs. Third, the graft is routed in a short course around the right margin of the heart without compressing the right atrium and right ventricle. While the disadvantages of this procedure are (1) it does not provide good access to the descending aorta if there is bleeding from the distal anastomosis; and (2) the heart is retracted cephalad, which will affect hemodynamics and require the assistance of CPB, but exposure is especially difficult in obese patients or those with barrel-shaped thorax. Aris and coworkers[9] reported ascending-to-descending aortic bypass with the aid of a heart-lifting device, Starfish 2 (Medtronic, Inc, Minneapolis, Minn), without CPB. We did not use this approach up to now. Aortoesophageal fistula and periprosthetic infections

are rare but devastating complications following dissection of the aorta and esophagus.[10]

The disadvantages of ascending-to-infrarenal abdominal aortic bypass grafting are, first, the graft must be long enough to reach the infrarenal abdominal aorta and an additional abdominal incision is necessary. We have adopted a midline incision from the suprasternal notch to a point halfway between the navel and the pubis. Wukasch et al[11] described an ascending-to-supraceliac abdominal aortic bypass grafting technique using a shorter abdominal incision: a standard median sternotomy extended caudad through the midline abdominal fascia to the level of the umbilicus. It needs to enter the peritoneal cavity and is more difficult to expose the abdominal aorta than the approach we used. Second, the long route of the graft carries the risk of intestinal complications from erosion or obstruction of adjacent organs. This procedure has its own advantages. (1) There is no need to retract the heart. It can be completed without CPB, and is especially suitable for patients with isolated complex coarctation and no concomitant disorders. (2) The long midline incision facilitates exposure of the ascending and infrarenal abdominal aorta, and makes anastomosis and hemostasis easier in comparison with ascending-to-descending aortic bypass. (3) The prosthesis extends over a longer distance and bends gently, thereby avoiding a sharp angle and consequent graft obstruction that might occur. (4) In this procedure, the distal anastomosis can be embedded in a retroperitoneal position and carefully covered with peritoneum, which, as a result, decreases the risk of fistula formation. Now, ascending-to-infrarenal aortic bypass has become the preferred procedure in our institute. We believe it is a simpler technique with fewer complications than the ascending-to-descending aortic bypass.

We hesitated to use extra-anatomic bypass grafting in adolescent children because of somatic growth.[12] During the follow-up, the infrarenal abdominal aorta was stretched into an arch-shape.

Stent implantation has been successfully performed in both native and recurrent coarctation of the aorta.[13] The mechanism of successful balloon dilation of coarctation involves tearing of the aortic intima and media. Thus, there is a risk of transmural tears and aneurysm formation with balloon dilation. So, aneurysm formation remains a concern. And there is less experience in adults whom the tissue is fragile and may have calcification or atherosclerosis.[14] The result of a combination of interventional and surgical management needs to be confirmed by long-term follow-up.

CONCLUSIONS

Extra-anatomic aortic bypass through median sternotomy or median sternotomy-laparotomy can be performed with low morbidity and mortality. This single-stage approach is suitable for patients with complex coarctation and concomitant cardiovascular disorders.

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AUTHOR CONTRIBUTIONS

Conception and design: RW, XH
Analysis and interpretation: QC, JZ
Data collection: XH, YL, CY
Writing the article: RW, WM
Critical revision of the article: RW, WM
Final approval of the article: RW, LS
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